

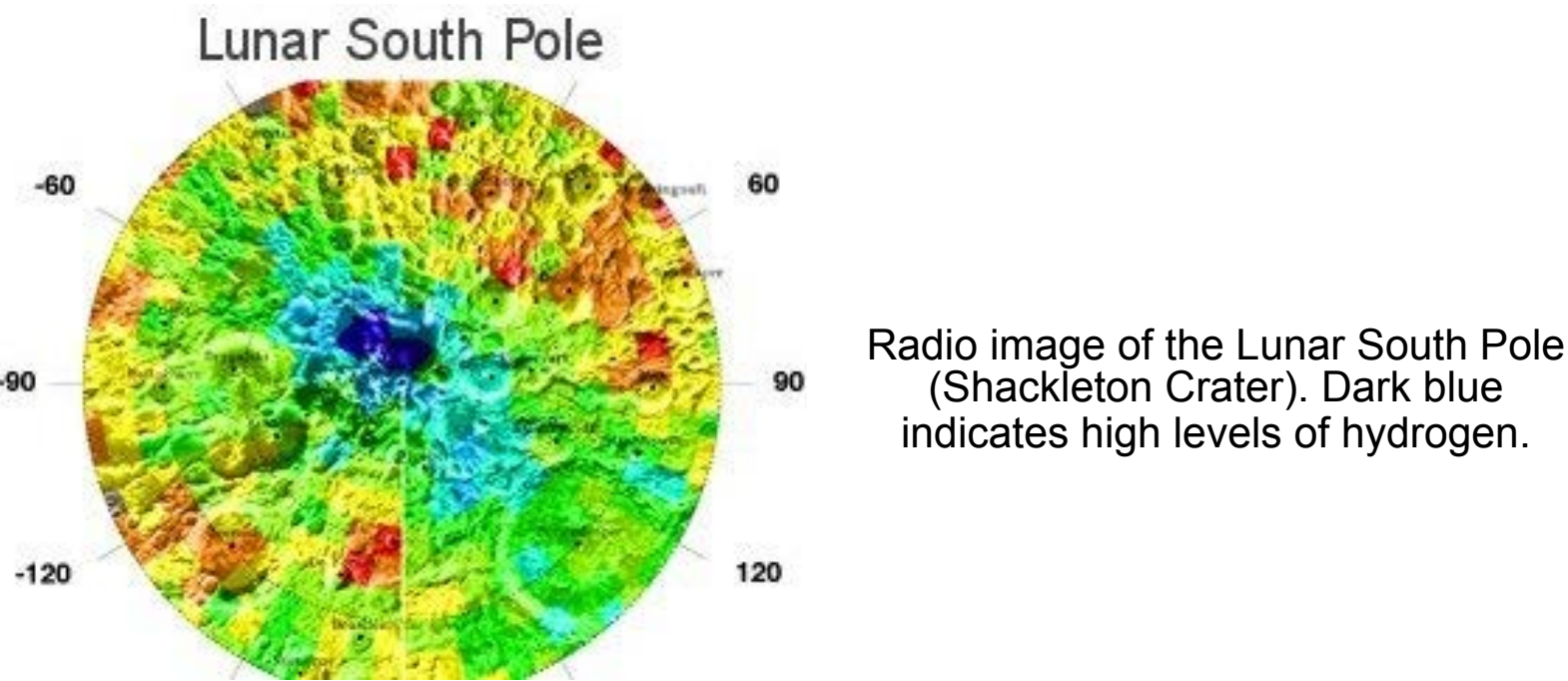
LUNAR GEOLOGY

The moon's surface is covered with a dirt like substance called regolith, which is a combination of many minerals. One, ilmenite (FeTiO<sub>3</sub>) can be broken down through a series of steps into valuable elements, especially titanium. Oxygen, another component of ilmenite, can provide astronauts with breathable air.



From Apollo 17, NASA

There is evidence that supports water on the moon, specifically in Shackleton crater- making it the desired location of our lunar facility. Spectrophotometer readings and radio images of the surface of the moon indicate high levels of hydrogen, a major component of water. Theoretically, high levels of hydrogen could indicate the presence of water ice.

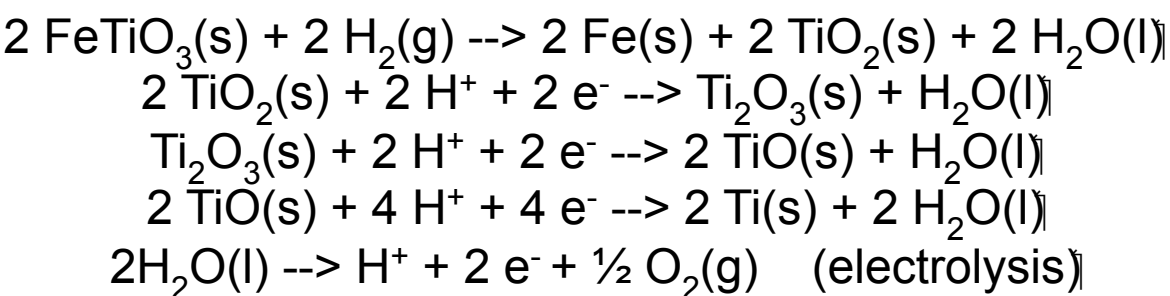


The bottom of Shackleton crater is in a permanent shadow, where the sun never rises more than 1.6 degrees off the horizon possibly causing water ice to form.

Along with ilmenite, lunar regolith contains other useful substances like helium-3 and quartz (SiO<sub>2</sub>). Helium-3 is an isotope of helium. In large quantities, it can be used to power radiation-free, environmentally-friendly nuclear fusion reactors. Quartz contains silicon, an element that is useful in the production of another green technology- solar power.

MATERIALS AND PROCESSING

The concept of this mission, initially, is to process ilmenite (FeTiO<sub>3</sub>) and water (H<sub>2</sub>O) into their profitable component titanium and life sustaining oxygen. Titanium can be extracted through the following process, which requires 2.22 kW.



Regolith is 30% ilmenite by composition. For every 1 kg regolith processed, 300 g ilmenite are produced. From this 300 g, 96 g titanium and 192 g oxygen are produced.

To produce oxygen, water ice would have to be pressurized to prevent sublimation caused by extremes in temperature and pressure. The liquid water would then be put through hydrolysis

Expansion of the lunar outpost would allow other lunar resources to be cultivated, i.e. silicon and helium-3. The FCC Cambridge process is being adapted for silicon. This process is similar to electrolysis, where the silicon is separated from the oxygen. Helium-3 could be released from regolith at extremely high temperatures.



**Sponsors:**  
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NASA New York City Research Initiative (NYCRI)  
Stevens Institute of Technology (SIT)

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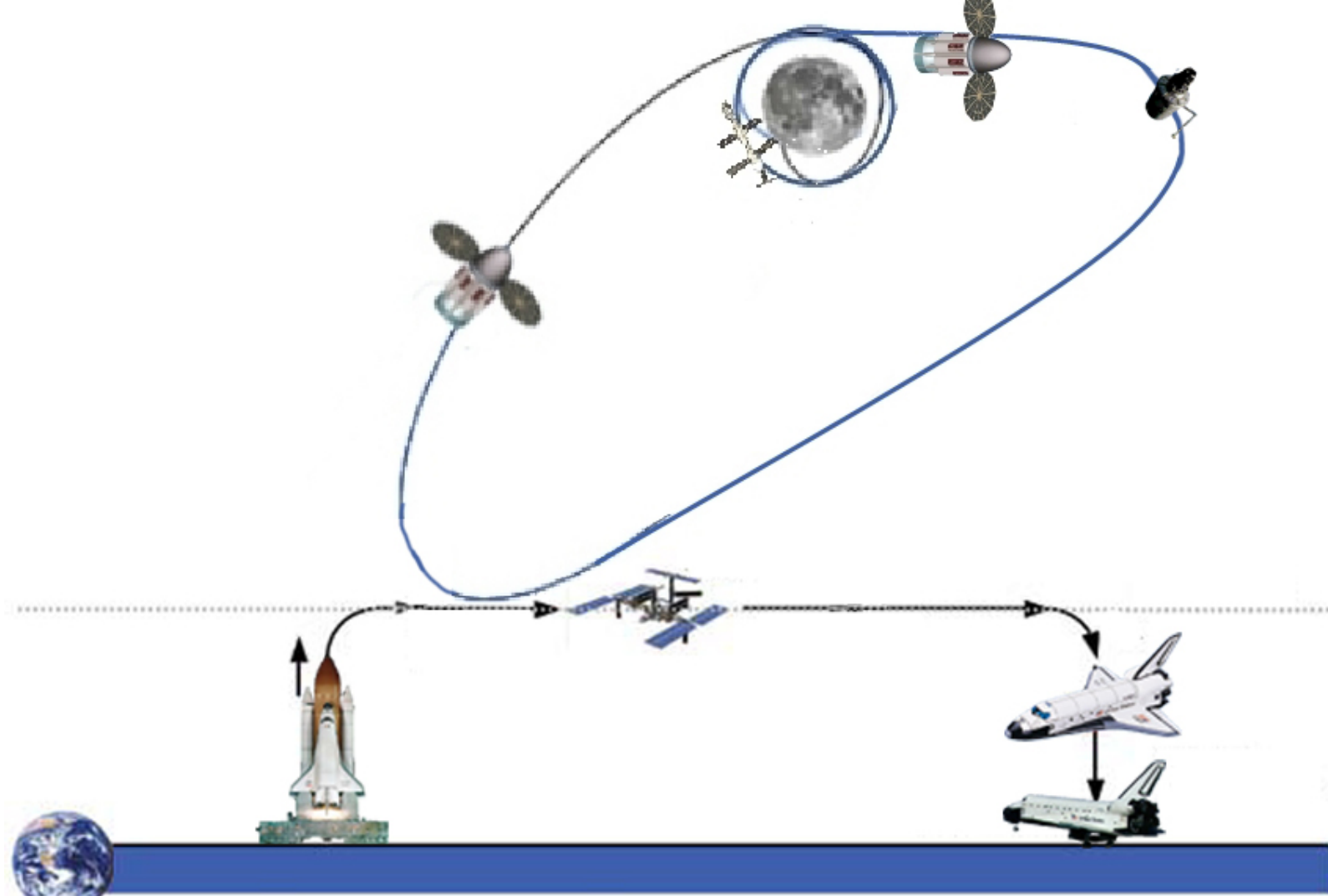
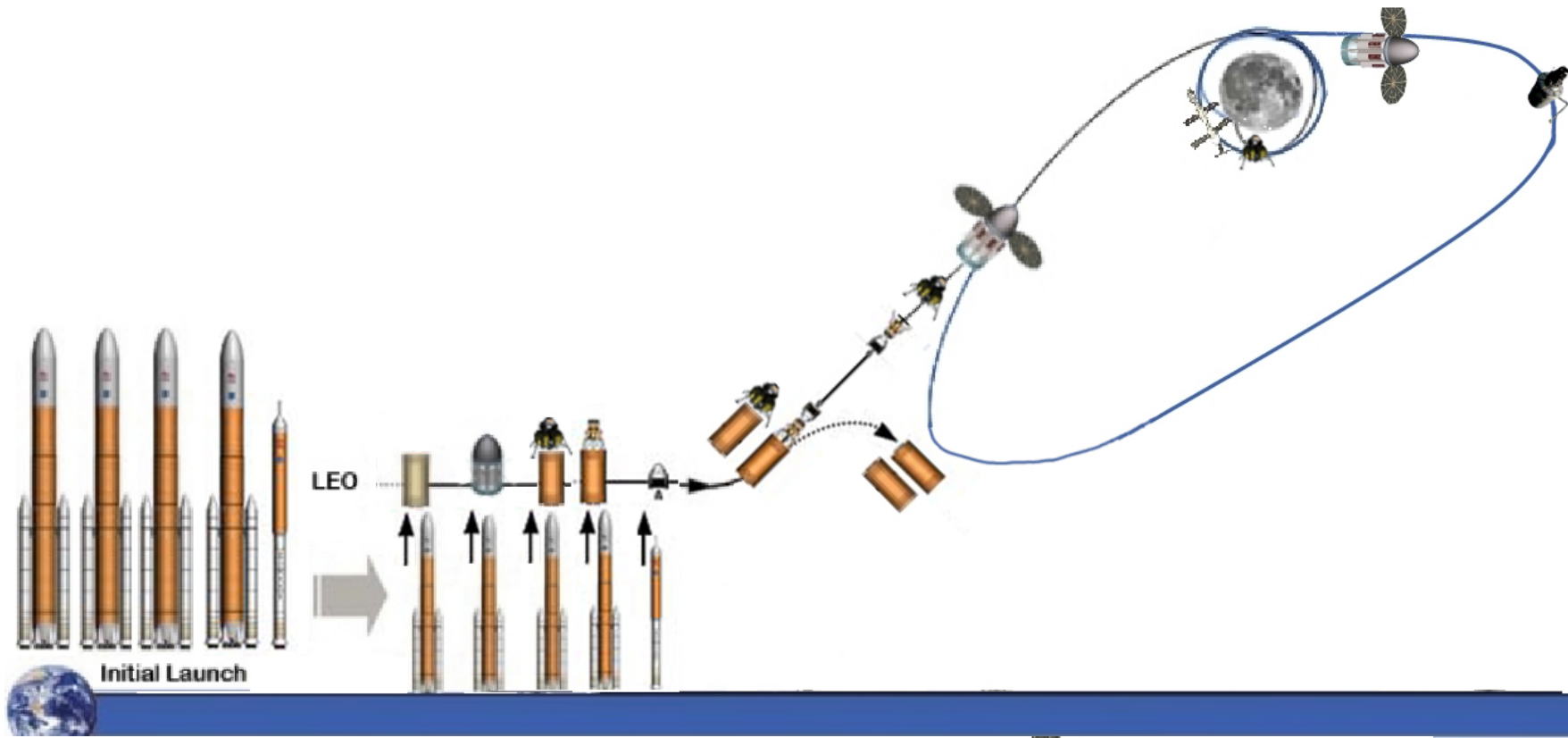
ONE GIANT LEAP FOR MANKIND:  
UTILIZATION OF VALUABLE LUNAR  
RESOURCES FOR FURTHER SPACE  
EXPLORATION

ABSTRACT

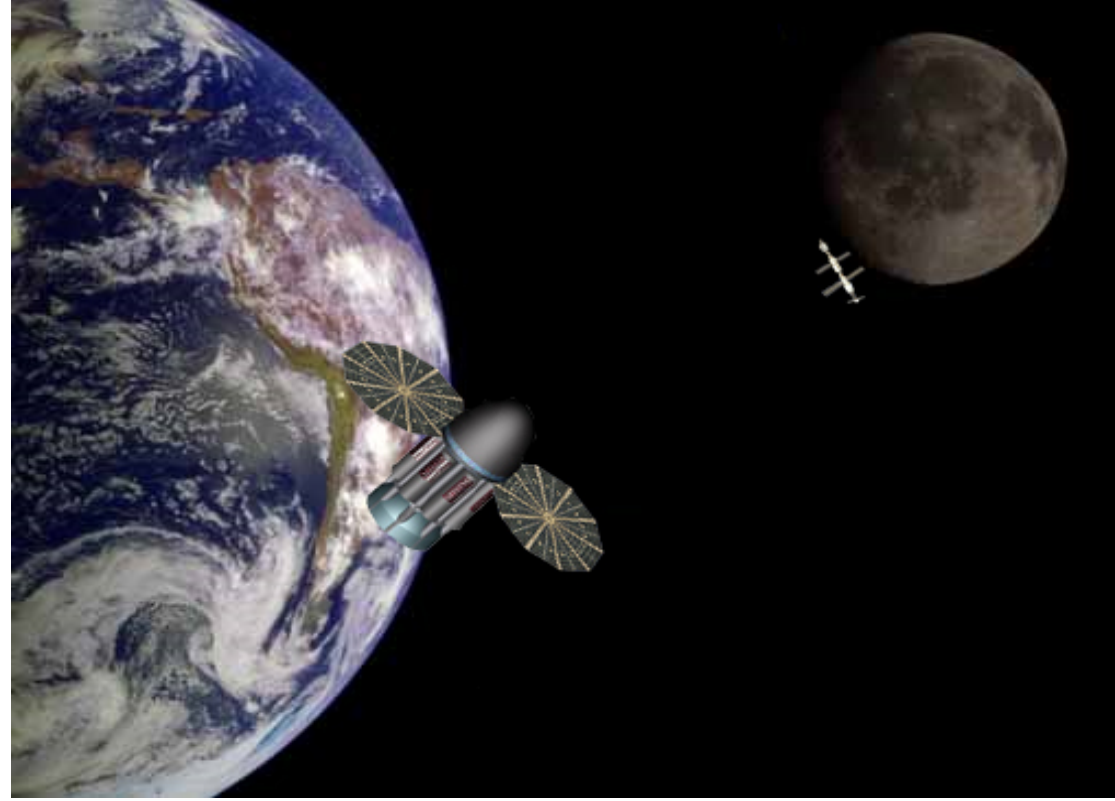
Space exploration has been severely curtailed since 1969, when NASA first sent a man to walk on the moon. An entrepreneurial enterprise to re-energize the space program in which lunar resources would be mined and processed is conceptualized in this research project.

This project involves the methodology consisting of the three components of lunar exploration: i) Earth-to-Moon cargo and personnel transport, ii) assembly of a sustainable lunar colony, and iii) the processing of minerals from lunar soil.

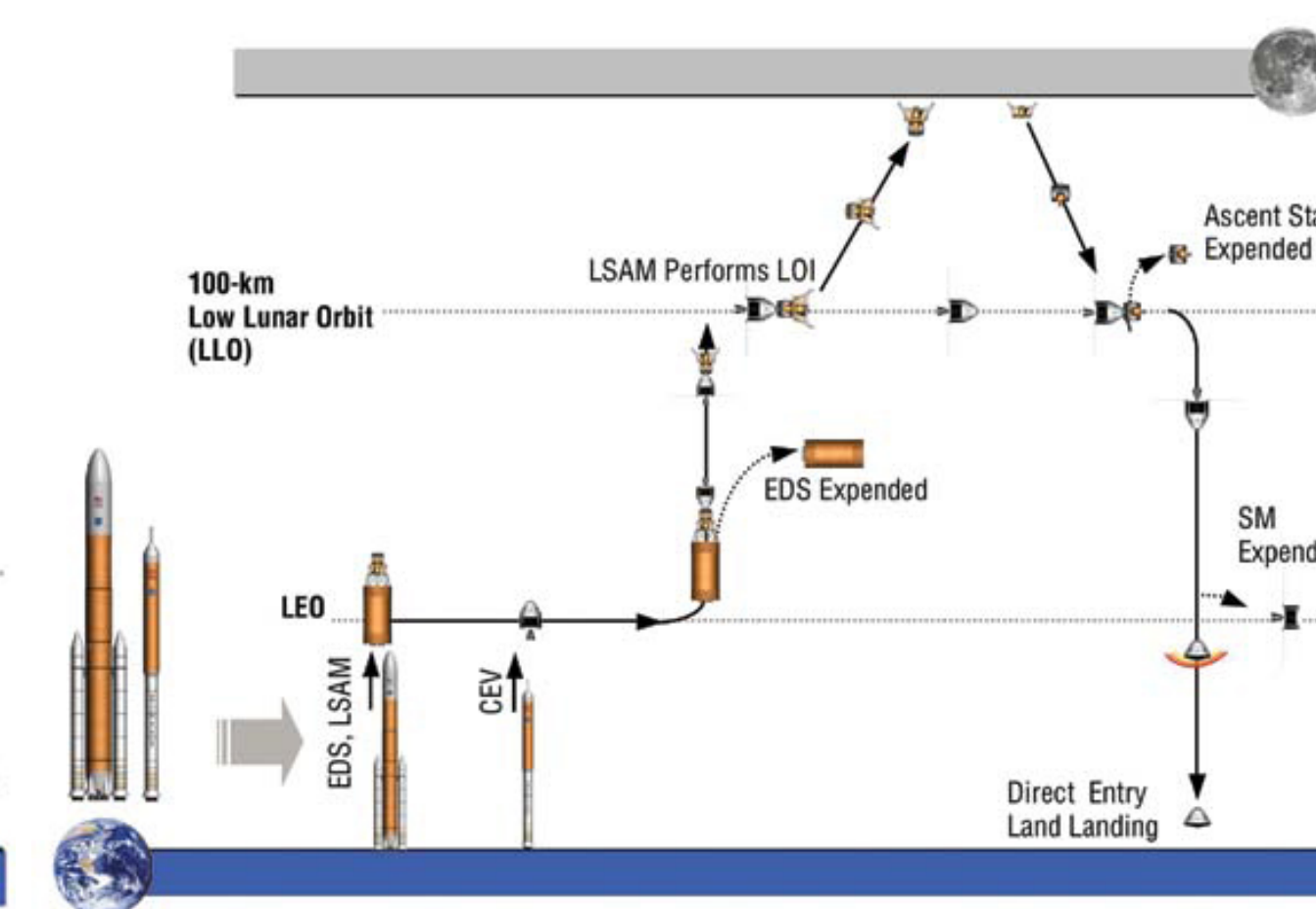
The lunar soil or regolith is comprised of many minerals. Various product outputs from processing regolith will be analyzed to determine the most profitable resource combination after twenty-five years of operation. Ilmenite (FeTiO<sub>3</sub>), a mineral in regolith, would be processed to yield solid titanium for spacecraft manufacture and oxygen to be used as breathable air for present or future exploration. Quartz, another mineral in regolith, would be refined into silicon for use in solar energy. In addition, Helium-3 would be separated from the regolith for use in nuclear fusion reactors.



Main Mission Architecture



LCTV in LEO in transit to LLO



System's Crew Rotation Architecture

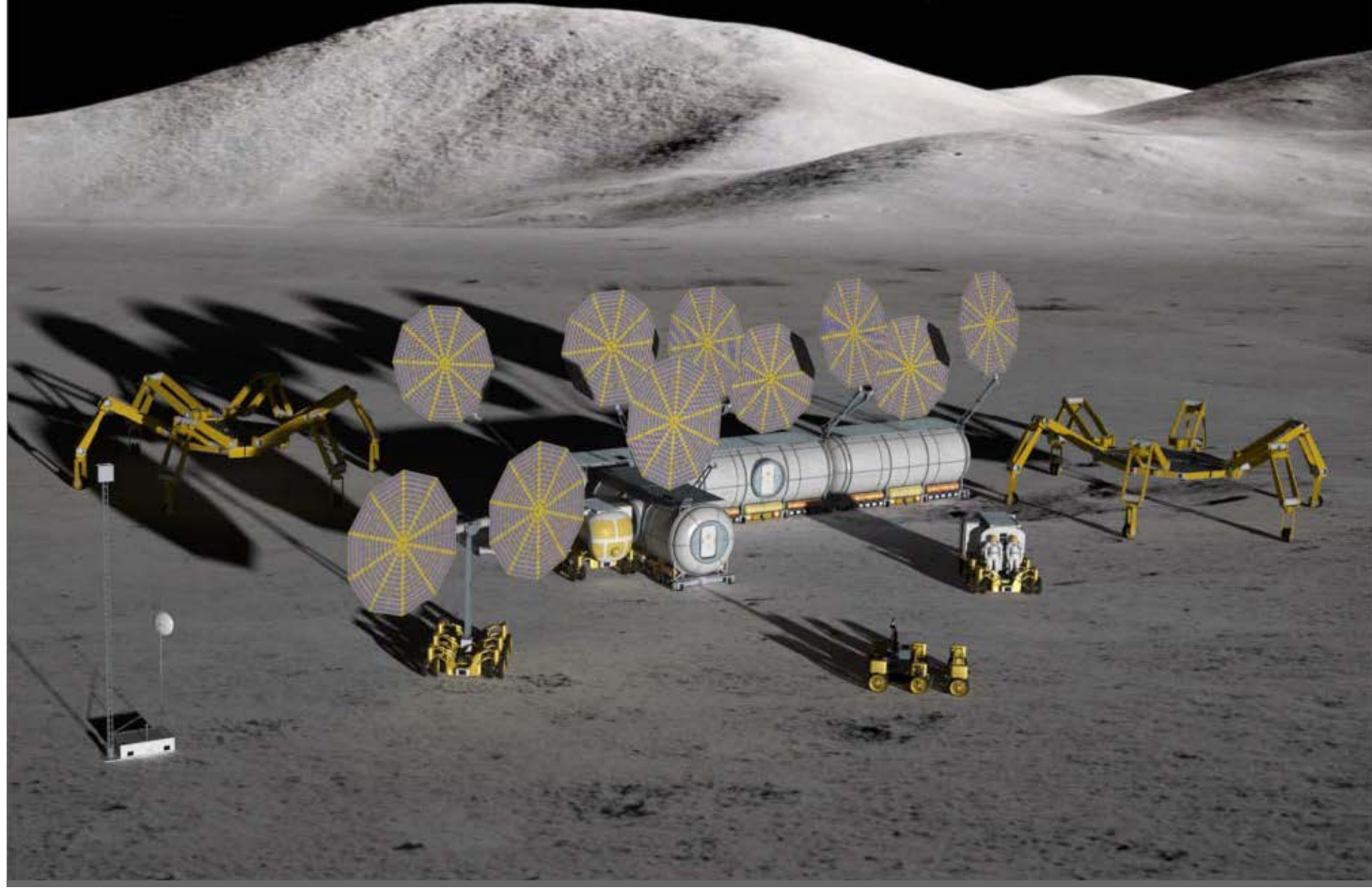
MISSION ARCHITECTURE

The proposed system has three operational regions with unique vehicles specific to each environment. The first region is the Earth's surface to Low Earth Orbit (LEO). Here, NASA's Cargo Launch Vehicle (CaLV), the Ares V rocket transports cargo up to LEO. Ares I Rockets to transport astronauts to LEO via a Crew Exploration Vehicle (CEV), and a Space Shuttle take goods back to the Earth's surface from the International Space Station.

Initially, the Lunar Cargo Transport Vehicle (LCTV) will deploy two new stations complete with docking modules for cargo and solar panels supplying energy, enabling pressurization. One station will be located at Low Lunar Orbit (LLO), and the other station will be located at the L4 Lagrange Point.

The second zone is between LEO, LLO, and the L4 Earth-Moon Lagrange Point. In this region, an LCTV transports cargo from LEO to LLO where it transfers payload to the LLO Station. Then, the LCTV can pick up base manufactured products for transport to the L4 Lagrange Point and then to LEO, where it refuels and picks up more cargo as required.

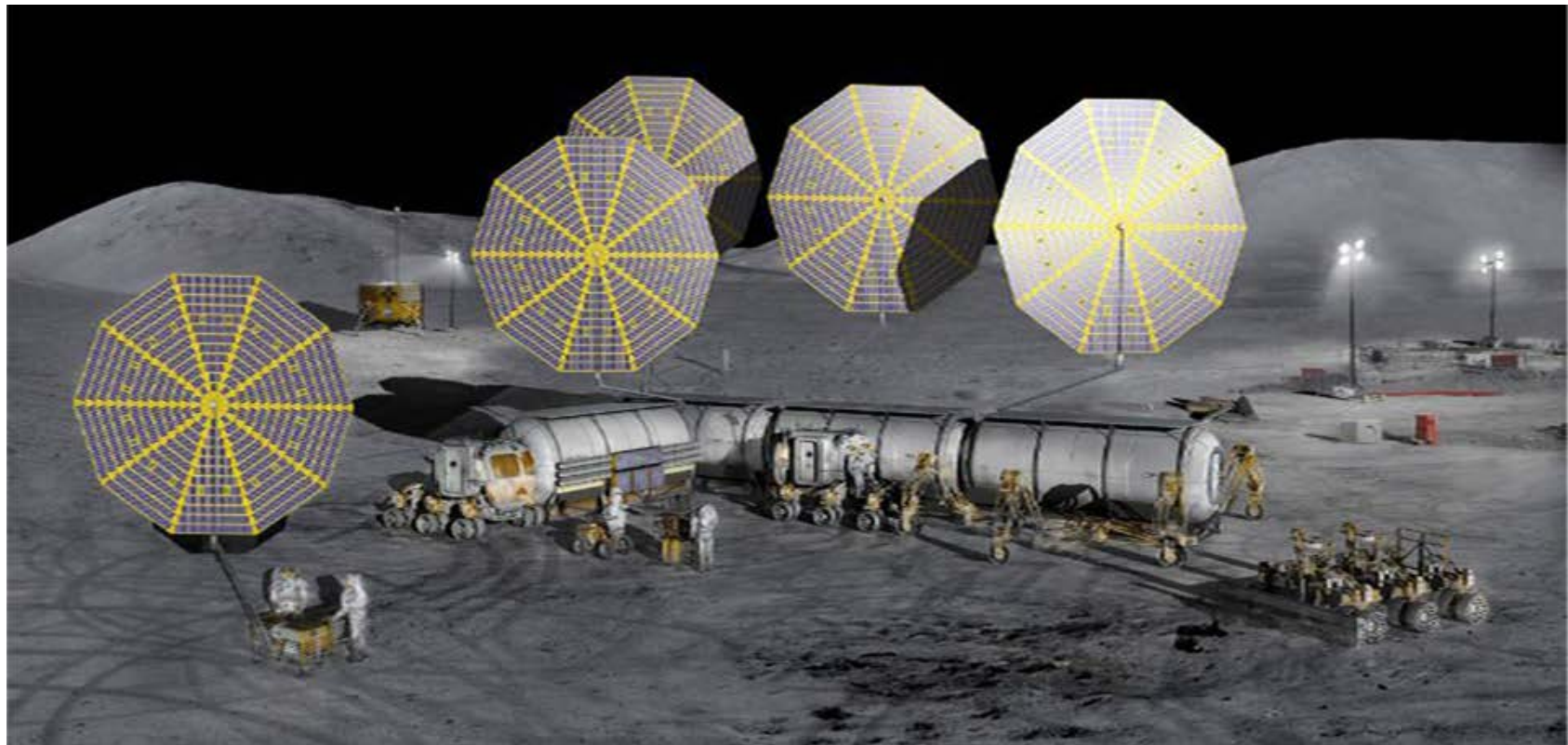
The third region is between LLO and the surface of the Moon. The Lunar Product Transport Vehicle (LPTV) brings material back and forth between the lunar outpost and the LLO Station.



Lunar Outpost

OUTPOST CHARACTERISTICS

The surface outpost is constructed of interlocking modules that are covered in regolith and powered by an array of solar panels. Additional modules are brought to the base as needed. The number of modules is dependent on the materials being mined at that time. The ground operation has two different classes of rovers that carry out base tasks. Mining rovers, or Miners, are a class dedicated to digging up regolith and bringing it back to the hub. There are also building rovers, or Builders, that are dedicated to erecting the outpost, making large scale repairs of the outpost, positioning equipment, and moving modules to where they are needed. The combination of builders and rovers are responsible for covering the living quarters in regolith during the construction of the outpost. Initially the outpost has three Miners and three Builders, and this small fleet is expanded upon every LCTV expansion flight.



POWER SUPPLY

Power for the lunar based system would be supplied by two 9-meter solar arrays, as described in the Lunar Surface Systems Project Overview given by Chris Culbert. These solar arrays have a net power generation of 11.2kW, and are equipped with 720 kWh regenerative fuel cells. As the base expands, more solar arrays would be added, according to necessity.

Estimates for the total power needed to keep a habitat functioning were based off of the design for a Minimal Functional Habitat, conceptualized by Dr. David L. Akin, Massimiliano Di Capua, Omar Medina and Adam Mirvis, from the Space Systems Laboratory in the University of Maryland. In their report, total power needed would peak at 2590 W, which makes the use of the 9-m arrays ideal. This habitat design allows for a crew of up to 4 astronauts, and includes the power necessary to keep the area heated, pressurized, lighted appropriately, and other necessities for optimized crew comfort and survival.

The Lunar Cargo Transport Vehicle draws its power from four solar arrays. These arrays each have a total power output of 546.8 W, with current photovoltaic cell efficiencies. The L4 Lagrange Point Station has similar energy requirements. The LLO Station, however, would require additional power and fuel to maintain orbit.

ACCUMULATED REVENUE FOR SYSTEM CONFIGURATIONS

Year	System Configuration 1: Ilmenite and Water Only	System Configuration 2: Ilmenite, Water, and Quartz Only	System Configuration 3: Ilmenite, Water, and Helium-3 Only	System Configuration 4: Ilmenite, Water, Helium-3, and Quartz
0	-\$21,564,740,323.88	-\$21,564,740,323.88	-\$21,564,740,323.88	-\$21,564,740,323.88
1	-\$26,597,184,696.51	-\$29,500,929,155.24	-\$63,354,645,310.38	-\$24,599,531,466.21
5	-\$63,731,844,426.26	-\$66,162,449,884.99	-\$108,420,461,897.89	-\$61,197,942,554.16
10	-\$108,664,743,100.33	-\$108,918,176,400.33	-\$108,420,461,897.89	-\$103,310,749,941.67
15	-\$151,838,774,591.85	-\$149,644,014,391.85	-\$151,523,229,059.32	-\$143,099,434,061.83
20	-\$193,620,586,600.83	-\$188,377,899,900.83	-\$192,947,614,994.68	-\$179,836,910,914.65
25	-\$233,270,705,405.03	-\$224,484,804,705.03	-\$231,164,925,164.27	-\$212,915,467,182.65
26	-\$240,816,318,285.87	-\$231,221,816,585.87	-\$238,362,322,131.42	-\$218,008,503,266.49

The first configuration only mines ilmenite and water for twenty-five years. The second mines ilmenite and water, and after five years also mines quartz for processing into silicon for the remaining twenty years. In the third configuration, ilmenite, water and Helium-3 are extracted from regolith for 25 years. The fourth configuration is a combination of systems two and three, where after five years of mining ilmenite, water and Helium-3 alone, quartz is processed into silicon, making it the most desirable configuration. The mission's cost can be reduced with technological developments in mission architecture from the Earth's surface to LEO and back. Discovery of other rare materials on the Moon can increase the desirability of future lunar exploration.